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Robert J. Milko

Science and Technology Division
Research Branch
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BACKGROUND PAPER FOR PARLIAMENTARIANS

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TABLE OF CONTENTS

Page

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POTENTIAL ENVIRONMENTAL EFFECTS OF THE PROPOSED JAMES BAY DIVERSION PROJECT (GRAND CANAL)

INTRODUCTION

The Hudson Bay drainage area includes more than three million square kilometres, has an annual average discharge rate more than twice that of either the Mackenzie or St. Lawrence Rivers, and contains the largest body of water in the world that virtually freezes over each winter and becomes ice-free during the summer; yet it has been only marginally studied.(1,2) In the 1970s, hydroelectric developments on rivers which flow into James Bay prompted an increase in studies of James and Hudson Bays with research predominantly focused on James Bay. It is from this scant information that predictions of the effects of terminating the flow of freshwater from James Bay into Hudson Bay must be made.

In view of the resurgence of interest in the "GRAND Canal" scheme,(3) which would involve the construction of a dam across James Bay,(4) an assessment of potential impacts warrants attention. In order to speculate on these impacts, the oceanographic parameters of Hudson and

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(1) Average annual discharge rate of Hudson Bay drainage area is 22,600 cubic meters per second (m^3/s).

(2) S.J. Prinsenberg, "Man-Made Changes in the Freshwater Input Rates of Hudson and James Bays," Canadian Journal of Fisheries and Aquatic Sciences, Vol. 37, 1980, p. 1102.

(3) GRAND is an acronym for "Great Recycling and Northern Development."

(4) Robert Bourassa, Power from the North, Prentice Hall, New Jersey, 1985, p. 133-157.

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James Bay must first be understood. Consequently, this report first briefly summarizes some of these parameters, with an emphasis on those of Hudson Bay. Second, the report examines some similar, large-scale diversions elsewhere, which should help to illustrate the effects or potential effects of large-scale water diversions. Thirdly, possible impacts on the oceanographic and ecological parameters of Hudson Bay and James Bay, resulting from the construction of a dam which would terminate the flow of freshwater between these bodies of water, are examined.

GENERAL DESCRIPTION

Hudson Bay is part of a large inland sea which is connected to the Atlantic Ocean by Hudson Strait and the Labrador Sea, and, to the Arctic Ocean by Fury and Hecla Strait. Hudson Bay has an average depth of 125 m and an approximate rectangular shape of 925 by 700 km. James Bay is much shallower, seldom deeper than 50 m, and with an average depth of 28 m; it is 150 km wide and 400 km long.

A. Circulation

Hudson Bay has generally been believed to behave as a huge estuarine basin with fresher, less dense water flowing out at the surface and denser, saltwater moving in at depth.(1) Because of sills and varying depths at the entrance to Hudson Bay, deepwater exchange appears to occur predominantly by way of one central channel, with some winter influx by way of a shallower channel to the north and west of Southampton Island. Saltwater inflow into Hudson Bay through these two channels has been estimated at 0.5×10^6 m^3/s and 0.05 to 0.1×10^6 m^3/s, respectively.(2) The water that enters the bay is heavier and sinks

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(1) R.J. Pett and J.C. Roff, "Some Observations and Deductions Concerning the Deep Waters of Hudson Bay", Le Naturaliste canadien, Vol. 109, 1982, p. 767.

(2) M.J. Dunbar, "Oceanographic Research in Hudson and James Bays," Le Naturaliste canadien, Vol. 109, 1982, p. 680.

below the surface layer and does not show up as surface flow.[1]

Figure 1 shows the summer surface circulation pattern of Hudson and James Bays. In Hudson Bay, the southeasterly surface circulation is predominantly wind-driven in the summer and autumn, resulting in a cyclonic pattern with an average speed of 5 cm/s. The circulation is also partially driven by density currents as a result of dilution because of freshwater runoff. Surface outflow is predominantly through Hudson Strait to the north (9 cm/s) and is seasonal in response to the freshwater input cycle. The absence of a northwestward return flow results in an upwelling region along the northwestern shore where deeper water partially replaces the offshore component of the surface flow to the southeast.

Circulation in James Bay is comprised of a cyclonic gyre, driven partly by wind stress and by runoff dilution. This also results in an estuarine circulation where cold saline water enters James Bay from Hudson Bay beneath the fresher surface layer[2] and exits in a strong northerly, surface outflow (15 cm/s in the summer) along the eastern shore into Hudson Bay.

B. Salinity, Temperature and Seasonal Distributions

Data in all seasons for Hudson Bay are lacking but are somewhat more complete for James Bay. Generally, the less saline water is found along the south and east shores of Hudson Bay,[3] and unlike the case in Hudson Strait, a temperature increase at large salinities associated with a deep layer of Atlantic water, is not found. Cross-sectional surveys have indicated that below the surface layer the water continually becomes colder

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(1) S.J. Prinsenberg, "Circulation Pattern and Current Structure of Hudson Bay," Canadian Inland Seas, Elsevier Oceanography Series (in press), 1985.

(2) Ibid., p. 1-11 of draft copy.

(3) S.J. Prinsenberg, "Time Variability of Physical Oceanographic Parameters in Hudson Bay," Le Naturaliste canadien, Vol. 109, 1982, p. 686.

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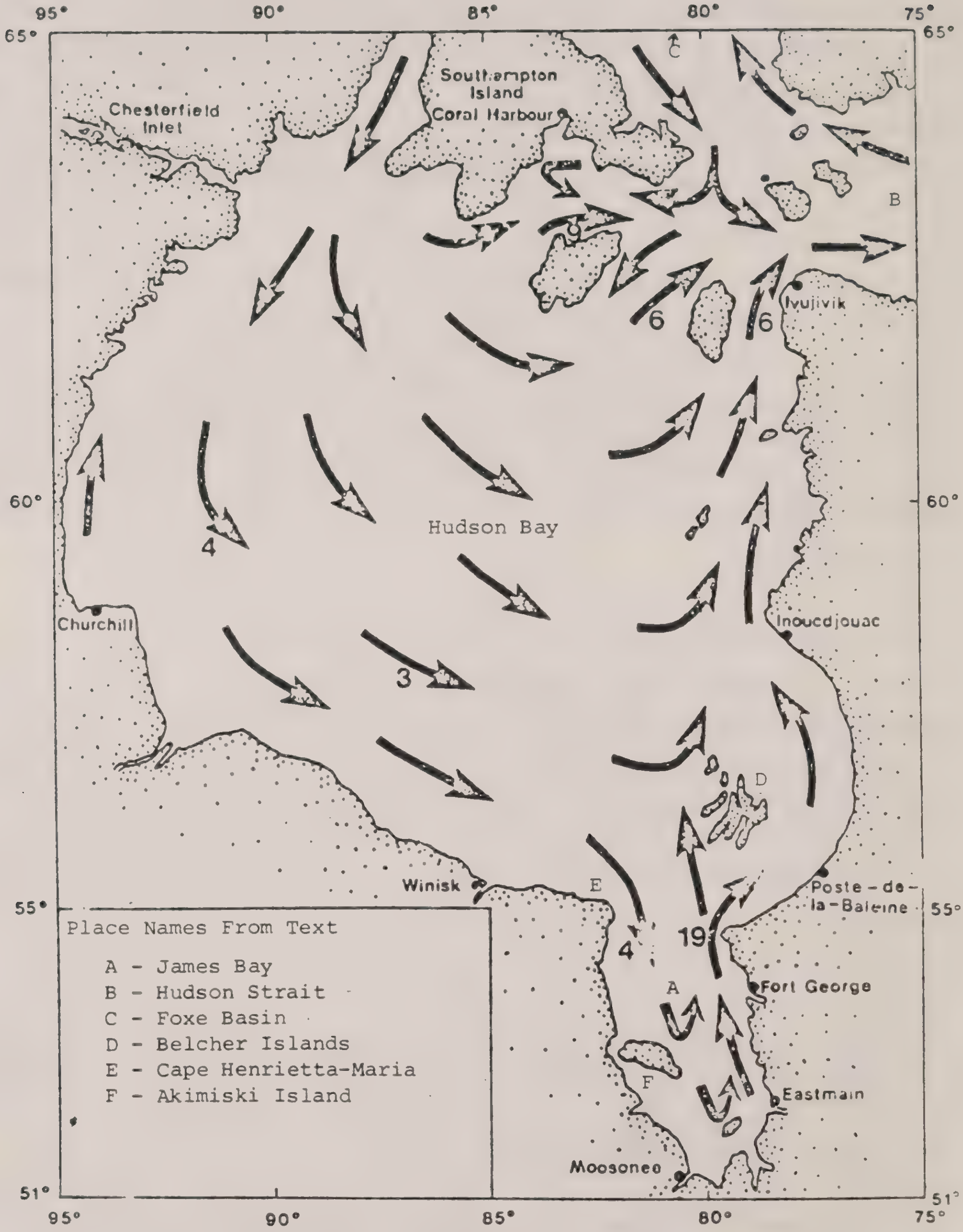
FIGURE 1: SUMMER SURFACE CIRCULATION PATTERN OF HUDSON BAY



Source: S.J. Prinsenberg, "Circulation Pattern and Current Structure of Hudson Bay", Canadian Inland Seas, Elsevier Oceanography Series (in press September 1985).

and more saline with depth. At 100 m, the water has an average salinity greater than 33‰[1] and is colder than -1.4°C. Offshore salinities of major rivers in James Bay can be as low as 10‰ with the lowest salinities occurring in the summer because of increased runoff and melting of the ice cover.[2]

A simple description of circulation involving these parameters can be envisioned as cold subsurface water with a salinity greater than 30‰ entering Hudson Bay from Hudson Strait, while the surface water, moving north along the eastern shore is a water mass warmed by solar radiation and diluted by runoff. The outflow temperature and salinity are somewhat modified by vertical mixing with the subsurface waters as they circulate through Hudson Bay.

Although insufficient data are available to accurately model seasonal variations of salinity and temperature, some general observations can be made. The pycnocline,[3] established in conjunction with surface runoff in the spring, progresses to greater depths as the season advances, reaching a maximum depth of 93.5 m at the end of the following winter (Figure 2). Below the pycnocline (average depth of 25 m) water properties remain relatively constant but, above the pycnocline, vertical mixing redistributes solar input to produce a relatively homogeneous water temperature which contains 74% of the total heat input to the bay.[4]

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(1) Note: ‰ means parts per thousand -- Atlantic Ocean surface water has an average salinity of 30‰. Sea ice has an average salinity of 5‰.

(2) S.J. Prinsenberg, "Salinity and Temperature Distributions of Hudson Bay and James Bay," Canadian Inland Seas, Elsevier Oceanography Series (in press), 1985.

(3) Pycnocline may be defined as a sharp boundary separating two liquid layers of different densities, e.g., a freshwater layer over a saltwater layer with little diffusion between them.

(4) S.J. Prinsenberg, "Freshwater Contents and Heat Budgets of James Bay and Hudson Bay," Continental Shelf Research, Vol. 3, No. 2, 1984, p. 198.

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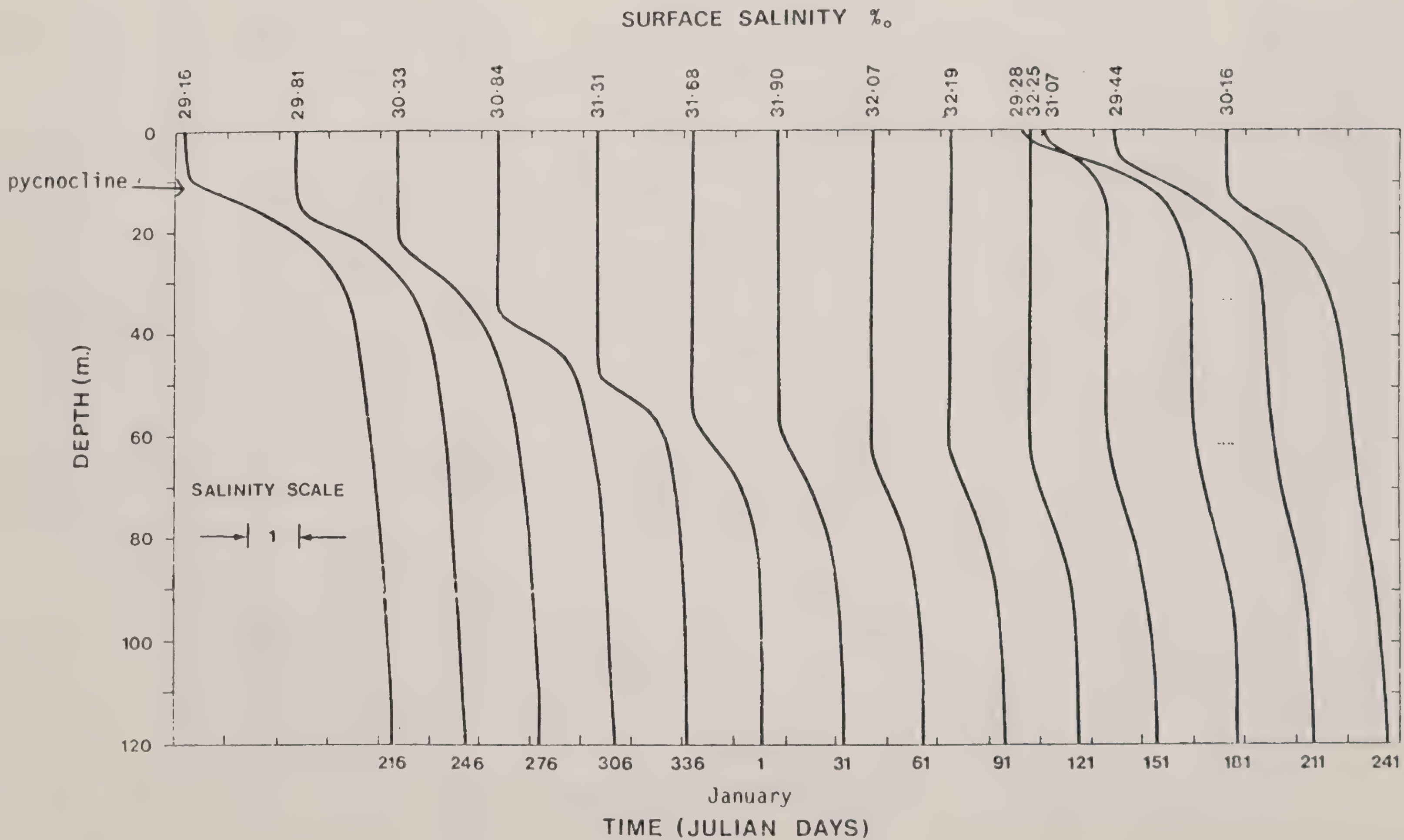
FIGURE 2: MODELLED SALINITY PROFILES OF HUDSON BAY AT A THIRTY-DAY TIME INTERVAL OVER A ONE-YEAR PERIOD



Source: S.J. Prinsenberg, "Salinity and Temperature Distributions of Hudson Bay and James Bay", Canadian Inland Seas, Elsevier Oceanography Series (in press), 1985.

C. Freshwater Input[1]

Because ice is relatively fresh (5‰), ice cover and runoff have been calculated to be major and equal components of the freshwater flux of Hudson Bay. Their individual contributions are described below.

In Hudson Bay the ice cover starts to form in northern areas by late October and continues to grow until a maximum cover is reached at the end of April. An average ice thickness of 1.75 m is found in southern James Bay but an average of only 1 m is found in northwest Hudson Bay. Polynyas (open water leads in the ice) are found predominantly along the northwest coast and east coast of Hudson Bay, both coasts of James Bay and west of the Belcher Islands joining the two mainland masses.[2]

Decay of the ice cover commences in late May, rapidly releasing this source of stored freshwater throughout June and July. Breakup in Hudson Bay, aided by predominant northwest winds, occurs from north to south and east to west. Although this fresh water addition from the melting ice is approximately equal in volume to that of runoff and will contribute to the estuarine cyclonic circulation of Hudson Bay, it would appear to have no net effect on the overall salinity of the bay. It does, however, contribute as much to the water column stability induced by the upper fresh water layer, as does the surface runoff.

In contrast to Hudson Bay, the ice of James Bay breaks up from south to north with the bay usually ice free by the end of July. The timing and pattern for James Bay's breakup is strongly dependent upon the large quantity of relatively warm, freshwater of the spring runoff.[3] Consequently, this surface outflow from James Bay initiates the early breakup of the ice in south east Hudson Bay.

Runoff is a function of both spring melt and precipitation. In Hudson Bay the mean runoff per unit drainage area increases from north to south with a maximum value in south James Bay. On a seasonal basis, a maxi-

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(1) Prinsenberg (1985), "Salinity and Temperature Distributions of Hudson Bay and James Bay", p. 7-18 (for this section unless otherwise cited).

(2) Energy, Mines and Resources Canada, The National Atlas of Canada, Macmillan Company of Canada Ltd., Ottawa, 1974, p. 13.

(3) Prinsenberg (1980), p. 1104.

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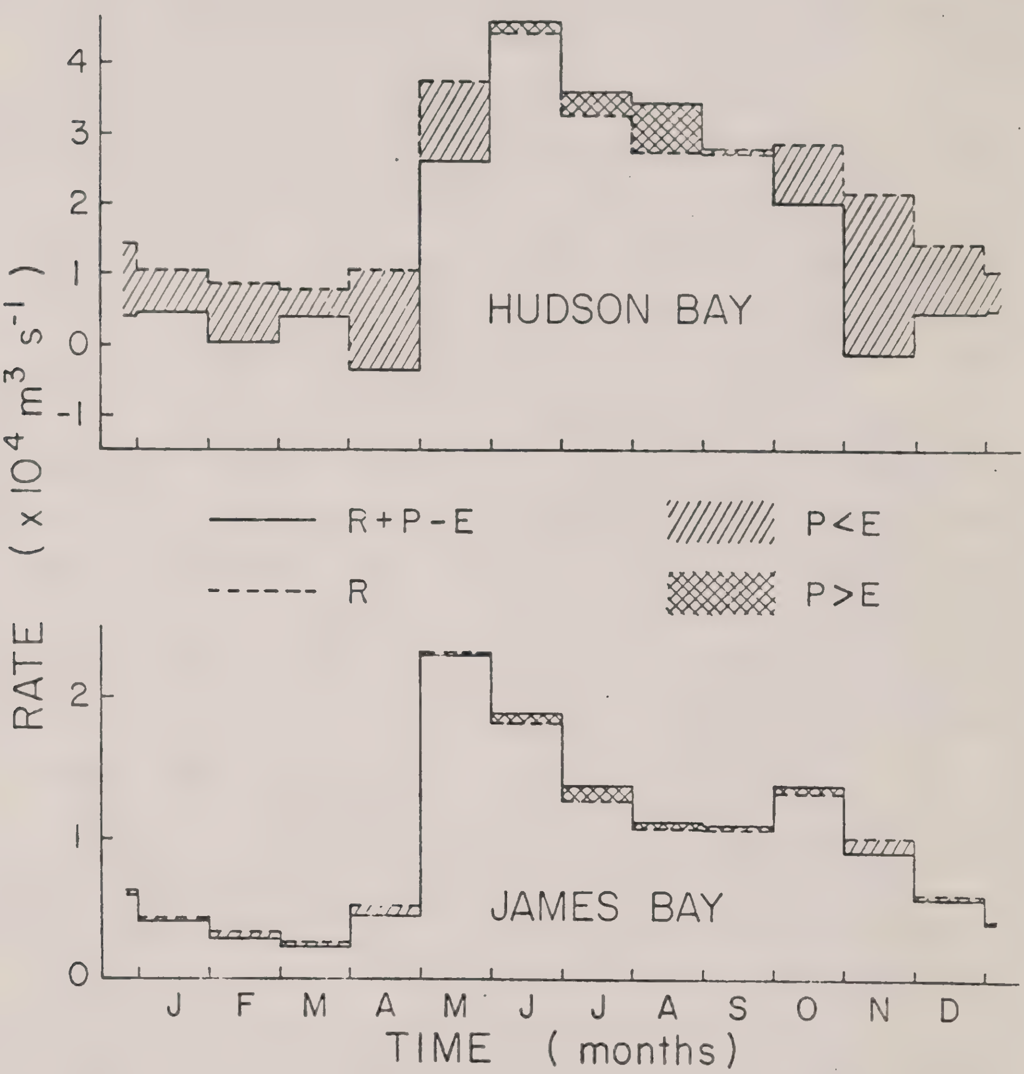
FIGURE 3: SEASONAL RUNOFF CYCLES FOR HUDSON BAY AND JAMES BAY



Note: R = Runoff
P = Precipitation
E = Evaporation

Source: S.J. Prinsenberg, "Salinity and Temperature Distributions of Hudson Bay and James Bay", Canadian Inland Seas, Elsevier Oceanography Series (in press September 1985).

mum runoff for both bays occurs with the spring freshet of May and June (Figure 3). In James Bay, however, a secondary peak of runoff occurs during the pronounced rainy season of the southern region. Here the precipitation rates are nearly double those of Hudson Bay and balance the loss of water resulting from evaporation. In contrast, Hudson Bay acts more as an oceanic region and loses more in evaporation than it gains from precipitation.

In summary, freshwater input cycles calculated from runoff, precipitation and evaporation can be divided into a winter and summer season. During the summer, the entire surface area of both bays gains a 10 cm layer of freshwater per month, which decreases to a 0.5 cm layer during the winter. Over the year, the region receives a 64 cm layer of freshwater (5.23×10^{11} m^3) which is equal to 0.5% of its total volume. Of this, James Bay accounts for 61% (3.17×10^{11} m^3), which indicates its importance to the freshwater budget of Hudson Bay.

The heat budget shows that the ice cover and the water column are the main benefactors of the incoming surface heat flux, and, that heat is lost mainly to turbulent fluxes which are very sensitive to the stability of the atmosphere. The results of the freshwater and heat budget show that the annual ice cover, runoff and heat content of the surface water are closely related. Changes in one will affect the others.

BASIC PRINCIPLES AND EFFECTS OF FRESHWATER FLOW

A primary reason for estuaries, embayments and continental shelves being fertile, productive regions is the supply of freshwater from land runoff which deposits nutrients directly and which, on entering the ocean, induces mixing and the entrainment of nutrient-rich deepwater to the surface. Particularly in higher latitudes, nearshore biological processes and adjacent ocean activities are attuned to this massive, seasonal influx. A freshwater flow encountering saltwater results in the formation of a density current or haline circulation system such as that which helps to drive the estuarine circulation of Hudson Bay. The effect of a density current is to impose a two-layer flow system which, in an estuary, causes the surface layer of freshwater to flow outward and the deeper (often nutrient-rich) bottom saltwater to flow inward. The magnitude of the

current will of course be proportional to the pressure difference and in an unregulated system, pulses of current occur as a result of seasonal runoff. It is possible that a reduction of a density current could result in a reduction in productivity.

An example is that of the St. Lawrence River and the Scotian Shelf and Grand Banks (Figure 4). The density current from the St. Lawrence freshwater flow results in deepwater from the continental shelf penetrating more than 1,500 km upstream without any significant contact with the freshwater. Over large distances as to the Grand Banks, there can be delays from several months to a year before a freshwater peak arrives. Regulation of the St. Lawrence River via the Manicougan-Outardes-Bersimis hydroelectric power complex commenced in the 1960s and retained up to 8,000 m^3/s by the spring of 1970 (one-quarter to one-third of the peak discharge of the St. Lawrence). This resulted in an approximate 1.3‰ increase in summer salinity of the surface layer at Cabot Strait and a drastic reduction in cyclic (seasonal) variation of salinities when compared to the unregulated condition.[1,2] Neu contends that this storage scheme had and continues to have an impact on the biological resources of the Atlantic coastal region. He estimates a 20-30% reduction of nutrients entering the system during the biologically active period and illustrates the relationship between varying flow rates and fish stocks, i.e., the larger the runoff, the greater the yield.[3,4,5] Data to prove the effect are admittedly masked by other possibilities such as changes in fishing levels.

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(1) H.J.A. Neu, "Man-Made Storage of Water Resources - A Liability to the Ocean Environment? Part I," Marine Pollution Bulletin, Vol. 13, No. 1, January 1982, p. 7-12.

(2) H.J.A. Neu, "Runoff Regulation for Hydro-Power and its Effect on the Ocean Environment", Hydrological Sciences Bulletin, Vol. 21, No. 3, September 1976, p. 433-444.

(3) Ibid.

(4) H.J.A. Neu, "Man-Made Storage of Water Resources - A Liability to the Ocean Environment? Part II," Marine Pollution Bulletin, Vol. 13, No. 2, February 1982, p. 44-47.

(5) Neu (1982), Part I, p. 12.

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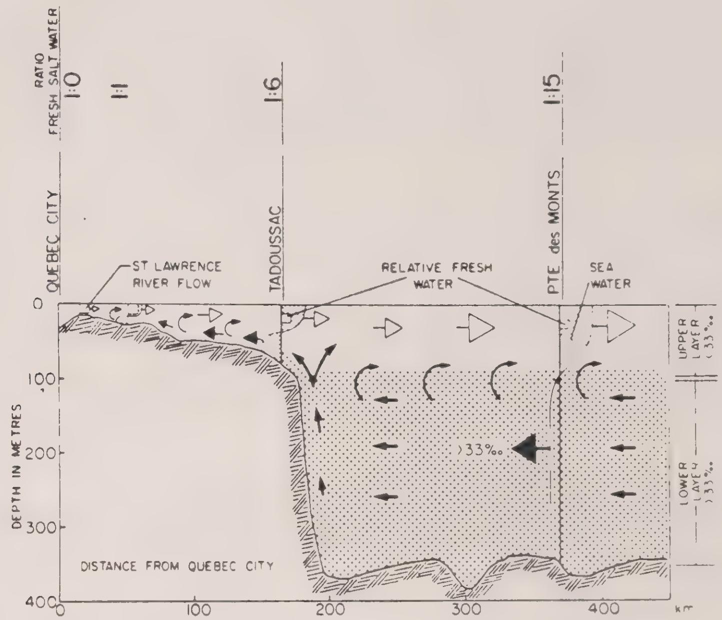
FIGURE 4: SCHEMATIC REPRESENTATION OF HALINE CIRCULATION (DENSITY CURRENT) IN THE ST. LAWRENCE RIVER SYSTEM



Source: H.J.A. Neu, "Runoff Regulation for Hydropower and its Effects on the Ocean Environment", Canadian Journal of Civil Engineering, Vol. 2, No. 4, 1975, p. 588.

Considerable concern has been expressed about possible climate modification as a result of large-scale water diversions of north-flowing rivers. In particular, plans of the U.S.S.R. to divert water from rivers flowing into the Arctic have led to some research into the impact of a reduction in the natural discharge on Arctic sea ice. Current water transfer proposals, scheduled to commence in 1986[1] involve the withdrawal of 60 km^3/yr from the European-north of the U.S.S.R. and 60 km^3/yr from the Siberian region, with a possible additional withdrawal of up to 100 km^3/yr during the 21st century. Because sea-ice concentration data for the Arctic and its marginal seas correlate significantly with variations in discharges of Siberian rivers, several mechanisms affecting localized and large-scale sea-ice cover are worthy of investigation. The first three of five mechanisms involve local or regional impacts:[2]

1) A reduction in riverflow could result in delayed removal of fast ice[3] or a reduction in removal of broken fast ice.

2) Reduced heat influx, i.e., warm freshwater, could result in early ice formation in the autumn.

3) A reduction of freshwater could result in a higher salinity which could lead to delayed or reduced ice formation in the autumn.

Hypotheses concerning mechanisms which have large-scale effects are more complex. Two are outlined below:

4) Density gradients (described earlier) result in an inflow of warm Atlantic water which, because of its high salinity (density), sinks below the colder, less dense Arctic water. The halocline in this Arctic region functions as a marked pycnocline and forms a barrier which suppresses heat flow from the deep Atlantic water

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(1) P.P. Micklin, "The Vast Diversion of Soviet Rivers," Environment, Vol. 27, No. 2, March 1985, p. 13.

(2) T. Holt et al., "Cryospheric Impacts of Soviet River Diversion Schemes," Annals of Glaciology, Vol. 5, 1984, p. 61-68.

(3) Fast ice was water adjacent to the shore that is now frozen throughout its depth.

to the surface. It has been suggested that a reduction in riverflow could lead to a subsequent thinning of the pycnocline allowing the deep, warm Atlantic layer to reach the surface. This could result in large ice-free areas and a general warming trend.

5) Conversely, less freshwater outflow could produce a weaker density current, reducing the strength of warm inflow from the Atlantic. This might result in colder overall temperatures and an increase in ice cover.

Modelling of the river flows and ice pack conditions suggests that a reduction of river discharges could result in local increases of ice in some areas and decreases of ice in others. On a large scale, modelling of mechanism 5) (above) suggests a reduced density current and an increase of ice cover are possible; mechanism 4) (above) could not be similarly modelled because of a lack of empirical data.

A numerical model, examining these diversions in the U.S.S.R., suggests some erosion of the stable stratification in the Kara and Barents Seas but not to the point of convective instability. As well, little change in the extent of sea ice, except for possible local minor thickening was predicted.(1)

Opinion is divided over whether the gross effects would be an overall warming or cooling, two diametrically opposed results; however, the weight of opinion and evidence points to a cooler Arctic.(2,3) If, however, a decreased ice pack was a result, it has been suggested that this, coupled with the greenhouse effect, could reduce rainfall in the very areas expecting to benefit from the diversions.(4,5)

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(1) A.J. Semtner, "The Climatic Response of the Arctic Ocean to Soviet River Diversions," Annals of Glaciology, Vol. 5, 1984, p. 229.

(2) Ibid.

(3) Micklin (1985), p. 44.

(4) J.P. Bruce and R.L. Pentland, Environment Canada, Water Resources of the 80s, a seminar on the Management of Water Resources, Institute of Public Administration of Canada, presented at Harrison Hot Springs, B.C., 24-26 April 1985, 22 p.

(5) J. Gribbin and M. Kelly, "Climatic Impact of Soviet River Diversions," New Scientist, 6 December 1979, p. 762-765.

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BIBLIOTHEQUE DU PARLEMENT

POTENTIAL EFFECTS OF CHANGES TO HUDSON BAY

A. Ice Pack and Climate

Although Hudson Bay is governed by somewhat different oceanographic parameters, there are enough similarities to the U.S.S.R. scenarios that the three mechanisms governing local effects on ice pack can be considered to be possible results of diverting the freshwater flow of James Bay south. The present effect of the Hudson and James Bays' ice pack on the weather patterns and flora in Central Canada is witnessed by the southward dipping of the treeline as the bay is approached. Considering the dependence of treeline on the delicate balance of climatic parameters, any modification to ice pack duration could affect the local or regional climate. Predictions of localized climate effects were made for much smaller-scale developments such as the La Grande on James Bay.(1) The large-scale effects of mechanism 4) (i.e., warming trend) seem unlikely for Hudson Bay as there is not a warm subsurface layer to be released to the surface. An effect on the pycnocline and the water column stability of Hudson Bay is, however, quite possible.

A one-dimensional oceanic mixed layer model, simulating the annual surface layer properties of Hudson Bay indicates their sensitivity to runoff modification. The model is simplistic, partly due to the lack of available data and the number of variables examined, but it does simulate some effects of hydroelectric developments. It does not, however, simulate a condition as extreme as withdrawal of all the freshwater contributed by James Bay (only one of many scenarios possible from the so far vaguely described GRAND Canal scheme). Results of the model indicate that the shallow surface pycnocline of Hudson Bay would be formed earlier in the spring, decreasing the surface layer temperature and salinity, and thus

(1) Environment Canada, James Bay Hydro-electric Project: A Statement of Environmental Concerns and Recommendations for Protection and Enhancement Measures, Lands Directorate (co-ordinator), Ottawa, 24 March 1975, p. 9-11.

stimulating an increase in ice formation. In the summer, the surface layer salinity would be higher and the temperature would be lower, which decreases the water column stability. As a result, the pycnocline would deepen, which would increase the deviations from normal conditions.[1] Although this indicates there is potential for ice pack and climate modifications, a more complex atmospheric model indicates that the sea surface temperature may be buffered against man-made changes. The model indicates that "a one-degree depression of sea surface temperature in the summer is slowly offset by increased heating and no noticeable change in temperature remains at the end of the fall."[2]

It should be noted that, in conjunction with Soviet water diversions, changes in the Arctic ice pack and the total amount of solar radiation absorbed in polar regions could have broad implications for global atmospheric circulation. As well, over the next century, the greenhouse effect could lead to warmer and wetter conditions in the James Bay area, perhaps resulting in a significant increase in runoff. The possibilities are both speculative and complex.

B. Primary Productivity

Based on the model simulating a 25% ice layer reduction, which is equivalent to a 50% reduction of James Bay freshwater flow, a total diversion of James Bay freshwater might result in only a 1‰ increase in salinity in the summer surface layer of Hudson Bay.[3,4] If this is the case, salinity modification of Hudson Bay may have less biological impact than one might imagine. However, further ramifications of the reduced stability and deeper pycnocline could involve a reduction in primary

---

(1) S.J. Prinsenberg, "Effects of the Hydroelectric Developments on the Oceanographic Surface Parameters of Hudson Bay," Atmosphere-Ocean, Vol. 21, No. 4, 1983, p. 418-430.

(2) S.J. Prinsenberg and M. Danard, "Variations in Momentum, Mass and Heat Fluxes Due to Changes in the Sea Surface Temperature of Hudson Bay," Atmosphere-Ocean, (in press) 1985.

(3) Prinsenberg (1983), Atmosphere-Ocean, p. 427-428.

(4) S.J. Prinsenberg, personal communication, September 1985.

productivity. Offshore phytoplankton are found in a 20 m layer below the pycnocline where their chlorophyll concentration ranges from 1.8 to 63 times surface chlorophyll layers. It is likely that this subsurface layer contributes significantly to the overall primary productivity of Hudson Bay.(1) If phytoplankton are somewhat restricted to this layer because of nutrient limitations above and light limitations below, a deeper pycnocline may result in the entrainment of nutrients below the photic limits of these phytoplankton.

Additionally, other aspects of circulation may affect production. For example, if the pycnocline were to deepen (recalling that mixing generally occurs above the pycnocline) the large, unoxidated nutrient reserves of the lower levels of the bay, which normally take four to fourteen years to turn over,(2) might be brought to the surface more rapidly and increase the nutrient composition in the photic zone. The mixing, however, would occur in the fall or winter, the time when the pycnocline is deep (see Figure 2). Although some species of epontic algae(3) photosynthesize at low light levels below ice (0.01% of surface irradiance),(4) it is not known whether the phytoplankton species in question have this ability. As well, the timing would not be characteristic of Arctic waters where a single peak of phytoplankton production normally occurs in the spring.(5)

The relative contribution of nutrients from James Bay to Hudson Bay is unknown. Preliminary budget calculations for the whole Hudson and James Bays system indicate that nitrate and total nitrogen contributions from deepwater mixing and land runoff are of the same order of

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(1) J.A. Anderson and J.C. Roff, "Subsurface Chlorophyll - a Maximum in Hudson Bay," Le Naturaliste canadien, Vol. 107, No. 4, 1980, p. 207-213.

(2) Pett and Roff (1982), Le Naturaliste canadien, p. 771-775.

(3) Epontic algae are unicellular algae associated with the lower interface of sea ice.

(4) G.F. Cota, "Photoadaptation of High Arctic Ice Algae," Nature, Vol. 315, 16 May 1985, p. 219-221.

(5) Anderson and Roff (1980), Le Naturaliste canadien, p. 211.

magnitude. Nitrification appears to be a limiting factor in Hudson Bay; however, nitrification does occur in winter in the neritic[1] James Bay environment.[2] Levels of nitrate and nitrite in the surface ice and in the snow cover are generally a factor of two or three greater than those in the water immediately below the ice. It is therefore possible that melting ice and snow may be an important nutrient source during the spring phytoplankton bloom.[3] In view of these processes and the probable large contribution of James Bay to Hudson Bay, withdrawal of the nutrients associated with the James Bay freshwater influx could severely affect the food chain.

Analysis of aperiodic phytoplankton blooms in Manitounuk Sound, a moderately saline (22‰) coastal embayment of southeast Hudson Bay, indicates that destratification mixes high salinity subsurface water to the surface which is not favourable for the phytoplankton species of the area. The destratification appears to result from current (windinduced) and tidal action and, although this upwelling provides required nutrients from below, it is the moderate salinities of the intermittent stable periods which are productive.[4] The construction of a dam across James Bay could affect aperiodic phytoplankton blooms of coastal embayments in several ways. It could potentially increase the moderate salinity of these localized embayments to a level too high to support production of the commonly-associated phytoplankton species. As well, the dampening effect of James Bay on the tidal action of Hudson and James Bays would be removed by the construction of the dam. The result might be an increase in tidal action (and that associated with wind) which might increase the depth and frequency of aperiodic destratification. Waters of higher salinity might be brought to the surface and the intermittent stable periods, required for production, might be reduced.

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(1) Neritic - defined as a region of shallow water adjoining the seacoast.

(2) Pett and Roff (1982), Le Naturaliste canadien, p. 776-774.

(3) N.G. Freeman et al., "Physical, Chemical and Biological Features of River Plumes Under an Ice Cover in James and Hudson Bays," Le Naturaliste canadien, Vol. 109, 1982, p. 745-764.

(4) L. Legendre et al., "Aperiodic Changes of Water Column Stability and Phytoplankton in an Arctic Coastal Embayment, Manitounuk Sound, Hudson Bay," Le Naturaliste canadien, Vol. 109, 1982, p. 775-786.

Long-distance and long-term effects are also possible. The freshwater contribution from James Bay is a significant part of the total signal from the Hudson/James Bay system which is detected down the Labrador coast.(1,2) The strength of the signal may be affected because of a reduced circulation in Hudson Bay, and the salinity of its waters entering the Labrador current would be increased. The changes would be received at the Grand Banks in the autumn, the Scotian Shelf during the winter, and Georges Bank probably during the spring. All these areas are productive fishing grounds possibly already suffering in production because of their reduced freshwater signals.(3)

C. Aquatic Food Chain

1. Plankton and Macrobenthic Fauna

A reduction in the primary productivity of Hudson Bay would eventually decrease productivity at all levels of the food chain. Resource inventories are scant and the relationships between components of all levels of the food chain in Hudson Bay are poorly understood. For example, ciliates are found in high abundance at the Belcher Islands in southeast Hudson Bay. Although their role has not been adequately described in any ocean, it has been suggested that they do play a significant role in the food chain at the Belchers, where they serve as important predators on phytoplankton and as prey for the larger omnivorous zooplankton.(4) Of the 235 phytoplankton species found in Hudson Bay, 42 are freshwater species, reflecting the large freshwater runoff into the bay. Their ecological role and contribution to total productivity has not been adequately identified although anadromous fish species are known to follow freshwater plumes out to the bay for feeding.

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(1) Steve Peck, Marine Environmental Data Services, Fisheries and Oceans (personal communication through P.A. Bolduc), 25 July 1985.

(2) Neu (1982), Part I, p. 8-9.

(3) Ibid.

(4) E.H. Grainger, "Factors Affecting Phytoplankton Stocks and Primary Productivity at the Belcher Islands, Hudson Bay," Le Naturaliste canadien, Vol. 109, 1982, p. 787-791.

The distribution of macrobenthic fauna in river estuaries is linked to salinity and organic matter content in the sediments. Macrobenthic fauna populations will therefore probably change as a result of a reduction of freshwater at river estuaries, particularly in the estuaries of the southeast coast of Hudson Bay where salinity might increase the most. Such change will be a function of the mode of reproduction of the species, their physiological response to physio-chemical variations and the changes that will occur in the sediments. Species with a pelagic mode of reproduction will probably invade new habitats in the more saline waters of estuaries faster than species without such a mode of reproduction.(1)

2. Fish

There are approximately 60 species of fish found at present in the estuarine fish communities of Hudson Bay and James Bay. Latitudinal differences are found in the composition of the communities with fewer species found in the north where arctic and subarctic species are more prominent.(2) The adaptability of fish species to salinity changes will play a predominant role in determining the composition of estuarine fish communities of the Hudson Bay coast after dam construction.(3) Considerable nearshore habitat would also be lost to marine species currently using this environment. There have been no scientific fish surveys of offshore James Bay and only one survey of offshore Hudson Bay, conducted in 1931. It is generally thought that the potential for a commercial fishery in either bay is low, although there has been some suggestion of potentially exploitable stocks of Greenland cod and capelin.(4)

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(1) J.F. Grenon, "The Macrobenthic Fauna of the Eastmain Estuary (James Bay, Quebec) Before the Diversion," Le Naturaliste canadien, Vol. 109, 1982, p. 793-802.

(2) R. Morin et al., "Estuarine Fish Communities of the Eastern James-Hudson Bay Coast," Environmental Biology of Fishes, Vol. 5, No. 2, 1980, p. 135-141.

(3) S. Ochman and J. Dodson, "Composition and Structure of the Larval and Juvenile Fish Community of the Eastmain River and Estuary, James Bay," Le Naturaliste canadien, Vol. 109, 1982, p. 803-813.

(4) J.G. Hunter, "Fishes and Fisheries," in C.S. Beals, ed., Science, History and Hudson Bay, Vol. 1, Queen's Printer, Ottawa, 1968, p. 372.

A survey of fisheries potential for supplying feed for 5,000 foxes at a fur farm in operation on the East James Bay coast is in preparation. Because of lack of support, the survey will be localized in the near-offshore of one village. Although fisheries potential in James and Hudson Bay has not been studied, it is anticipated that it would be negatively affected by the proposed scheme for the reasons outlined above, and as a result of the anticipated reduction in primary production.

Impounding James Bay would have similar implications for ecological productivity in the newly-formed lake. Virtually all marine organisms would be destroyed. Freshwater fish species presently dominant in Rupert's Bay(1) are the most likely to dominate in the impoundment.(2) However, additional problems might be anticipated as experience has shown that newly-created northern reservoirs are generally unproductive and fail to support viable commercial fisheries. In some small Arctic lakes, a salt layer is found at depths resulting in a gradient so strong that the lower layer never mixes with the surface, loses its oxygen content and becomes unproductive. In addition, northern impoundments have been shown to release contaminants which may accumulate in fish tissues, rendering them unfit for human consumption.

The transfer scheme would also provide the opportunity for inter-basin transfer of exotic species north to south and vice versa. These could include plankton, bacteria, viruses, fish species and their associated parasites (e.g., lamprey) into the James Bay impoundment.

3. Mammals

Little information is available on marine mammals of Hudson Bay or James Bay. Ringed seals and bearded seals are the predominant seal species and it is likely that they, as well as other marine mammals, would be negatively affected by a reduction in productivity at various levels of the food chain. Ringed seals require fast-ice for breeding whereas bearded

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(1) Morin et al. (1980), p. 135-141.

(2) J. Dodson, Université Laval, personal communication, September 1985.

seals are usually associated with moving pack ice and shallow banks that are free of land-fast ice in the winter.(1) Changes in ice pack regimes may affect either or both species. Ringed seals are found on all coasts of both Hudson Bay and James Bay, where their populations have respectively been estimated at 455,000 and 61,000.(2) The only population estimate for bearded seals is a 1958 figure of 84,000 in Hudson Bay.(3) Smaller populations of harbour seals, which require ice-free conditions in the winter, occur sparingly at isolated localities along all coasts, while small numbers of harp seals are found as far south as the Belcher Islands in the summer. Again, changes in the ice pack, notably a reduction of open water, could result in a reduction of their population. Walrus population estimates in the eastern Canadian Arctic are incomplete. In Hudson Bay, the main concentration is at northeastern Coats Island and southeastern Southampton Island where they are found during all seasons, with an estimated summer population of 2,000. In the 1950s and 1960s, the walrus population of Foxe Basin and Hudson Bay together was estimated at 8,500. They were found on both coasts of Hudson Bay and as far south as the Belcher Islands.(4)

Polar bears are directly dependent on seals as their main food source and would be affected by any long-term changes in seal populations. The large numbers of polar bears found on the coasts of Hudson Bay and northern James Bay during the summer and fall, and on islands in northern James Bay, could lose important denning areas due to flooding and construction. In particular, areas around Cape Henrietta Maria, which is a

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(1) A.W. Mansfield, "Seals and Walruses," in C.S. Beals, ed., Science, History and Hudson Bay, Vol. 1, Queen's Printer, Ottawa, 1968, p. 379-382.

(2) A 1975 estimate in: Department of Fisheries and Oceans Canada, Brief submitted to the Royal Commission on Seals and the Sealing Industry in Canada, Vol. 1, May 1985, p. 95.

(3) Mansfield (1968), p. 382.

(4) R.R. Reeves, "Atlantic Walrus (Odobenus rosmarus rosmarus): A Literature Survey and Status Report," Wildlife Research Report 10, U.S. Department of the Interior, Fish and Wildlife, Washington, D.C., 1978, p. 16.

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likely candidate site for dam construction, support a large population of polar bears.(1)

White whales (also known as belugas) are the main species of whale found in Hudson Bay. The most recent report estimates that a population of 8,000 to 9,000 belugas summer in western Hudson Bay and winter in open areas of Hudson Strait and Ungava Bay.(2) Other evidence suggests a portion of the population uses the polynya of northwest Hudson Bay and James Bay in winter.(3,4) Additionally, a small population of a few hundred, reduced from an estimated historical population of 5,000, spend the summer on the east coast of Hudson Bay.(5)

Estuaries appear important to Belugas, serving as feeding grounds, areas for as yet unexplained social behaviour and as calving grounds. It is hypothesized that the higher water temperatures of estuaries may lessen the shock of birth and reduce heat loss in the first few days after birth until sufficient subcutaneous fat has been acquired.(6) Loss or alteration of estuaries, which appear to be traditionally used, could further affect whale behaviour (i.e., migration pattern), reproductive success or both. At present there is considerable concern for the beluga populations because of continued harvesting by native peoples and because of effects of present hydroelectric developments. As the distribution and

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(1) J.P. Prevett, "The Status of Polar Bears in Ontario," Le Naturaliste canadien, Vol. 109, 1982, p. 933-939.

(2) K.J. Finley et al., "The Belugas (Delphinapterus leucas) of Northern Quebec: Distribution, Abundance, Stock Identity, Catch History and Management," Canadian Technical Report of Fisheries and Aquatic Sciences, No. 1123, November 1982, p. 13.

(3) C.J. Jonkel, "White Whales Wintering in James Bay," Journal Fisheries Research Board of Canada, Vol. 26, No. 8, 1969, p. 2205-2207.

(4) D.E. Sergeant, "Biology of White Whales (Delphinapterus leucas) in Western Hudson Bay," Journal Fisheries Research Board of Canada, Vol. 30, No. 8, 1973, p. 1065.

(5) Finley et al. (1982), p. V.

(6) Sergeant (1973), p. 1080.

movements of belugas are greatly influenced by ice conditions,[1] changes in ice pack regimes may have significant consequences. In conjunction with the possibility of lower water temperatures, a reduction in circulation of Hudson Bay could threaten the existence of polynyas. A reduced circulation could also reduce the upwelling of nutrients that occurs in the northwest of Hudson Bay, an area which appears biologically important for other marine species as well. A closing of open areas would be disastrous for any non-migratory populations of marine mammals.

An endangered population of possibly less than 100 bowhead whales inhabits northern Hudson Bay, most probably on a year-round basis, although once again data are limited. This Hudson Bay/Foxe Basin population is known to summer near Southampton Island in the same northwest area as the beluga whales, although possibly displaced a little north because of competition. It is not known whether the whole summer population winters in Hudson Bay but sightings have been made near Southampton Island, in the Foxe Basin shore leads and polynyas, and in the dense shifting pack ice of northeast Hudson Bay and west Hudson Strait.[2,3]

A strong, circumstantial argument suggests that ice conditions affect the survival of bowhead whales. An increase in ice cover could increase the possibility of entrapment in the ice, as bowheads tend to remain near the edge of ice, and would restrict their movement to preferred feeding grounds.[4] An increase in ice cover and a decrease in productivity in the food chain would not be beneficial to the population's present tenuous existence.

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(1) Finley et al. (1982), p. 2.

(2) R.R. Reeves et al., "Distribution and Migration of the Bowhead Whale, Balaena mysticetus, in the Eastern North American Arctic," Arctic, Vol. 36, No. 1, March 1983, p. 5-64.

(3) P.L. McLaren and R.A. Davis, Winter Distribution of Arctic Marine Mammals in Ice-Covered Waters of Eastern North America, unpublished OLABS Program Report, 1982, p. 63.

(4) E.D. Mitchell and R.R. Reeves, "Factors Affecting Abundance of Bowhead Whales (Balaena mysticetus) in the Eastern Arctic of North America, 1915-1980," Biological Conservation, Vol. 22, 1982, p. 59-78.

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D. Waterfowl, Shorebirds and Seabirds[1]

1. Waterfowl

The Hudson Bay and James Bay coasts are a major migration pathway for many species of geese and ducks en route between breeding and wintering areas. Approximately 2.5 million Lesser Snow Geese and 200,000 Canada Geese use staging areas on the coastal marshes of the Hudson Bay Lowland during spring and fall migration. In an average year, 1.5 million of the Lesser Snow Geese use the James Bay coastal areas.[2] The high fertility and productivity of the coastal zone support a wide range of food species which enable reproduction, growth of juveniles and fattening of all ages prior to the fall migration. In the spring, Lesser Snow Geese and Canada Geese are able to maintain weight for the final migration to their breeding areas by feeding on early exposed new growth and the perennating organs of arrowgrass. A major breeding colony of Lesser Snow Geese is located just west of Cape Henrietta Maria, with smaller breeding areas located on Akimiski Island near Churchill and in the vicinity of Eskimo Pt., N.W.T. (i.e., on Hudson and James Bays). Approximately 75% of the Atlantic Brant goose population is concentrated on the eel grass beds of the Quebec coast and parts of the Ontario coast of James Bay, and almost the whole North American population of Black Scoters may stage in southern James Bay (up to 320,000 in the fall). Additionally, many other species of waterfowl use the inshore intertidal and brackish coastal habitats which are very susceptible to changes in salinity. Major species include Black Duck, Pintail, Mallard, Wigeon, Green-winged Teal and Scaup. Mergansers and loons make extensive use of offshore waters for feeding and significant numbers of Common Eider spend the winter in James Bay. Although spring migrants use the southern James Bay shoreline the most heavily because it is the first section to melt, the coast of Hudson Bay is also used.

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(1) References for this section are a series of four papers in: Le Naturaliste canadien, Vol. 109, 1982, p. 895-932, in addition to personal communication with the Canadian Wildlife Service, Ottawa, August 1985, unless otherwise cited.

(2) J.P. Prevett et al., "Fall Foods of Lesser Snow Geese in the James Bay Region," Journal of Wildlife Management, Vol. 43, No. 3, 1979, p. 737-742.

2. Shorebirds

Probably the entire Hudson Bay population of Hudsonian Godwits use staging areas on the west coast of both bays to accumulate fat reserves that are essential for their direct flight to South America. They, as does probably the entire North American population of Red Knots use the lower intertidal zone, which would be destroyed in James Bay and possibly severely altered in Hudson Bay by the proposed project. Both are species for which there is a considerable conservation concern at present. Other important species include Dunlin, Black-bellied Plover, Golden Plover, Semi-palmated Plover, Greater and Lesser Yellowlegs, Sanderlings, four species of Sandpiper, Whimbrel and Marbled Godwit. The coasts of both bays are also used by the nearly-extinct Eskimo Curlew. Effects of dam construction would almost certainly be negative, particularly in James Bay (e.g., delayed ice breakup, lower productivity of marshes and invertebrates and alteration of seasonal resources) and could result in the destruction of all or a substantial portion of many North American migratory bird populations.

3. Seabirds

The area of northern Hudson Bay and west Hudson Strait supports the third largest seabird population in the Canadian Arctic, dominated by the Thick-billed Murre. The absence of other common species and the rapidly fluctuating population of the Murres suggest a delicate balance of food supply and population size. A reduction in food supply, one possible effect of terminating the flow of James Bay, might seriously affect the Murre population. Again, further study of oceanographic processes and their effect on food reserves is needed.

ADDITIONAL EFFECTS AND CONCERNS

"James Bay may be interpreted as a sediment sump for the centre of the continent."(1) Rivers are estimated to bring 4.12×10^7

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(1) K. Kranck and A. Ruffman, "Sedimentation in James Bay," Le Naturaliste canadien, Vol. 109, 1982, p. 353.

tonnes of sediment per year into James Bay.[1] Although this would only form a 0.33 mm layer if distributed evenly over the whole bay, the dam construction could alter the present patterns of sediment deposition, complicating engineering processes of water transfer, and affect water quality and aquatic life within the embayment. With a removal of estuarine circulation it is likely that coarse suspended particles would tend to settle out of the water column sooner, resulting in the formation of river deltas. In contrast, the very fine sediments would tend to stay in suspension longer because a freshwater regime would result in less flocculation and precipitation.[2] Potential effects could be a reduction in primary productivity as less light becomes available and an increased potential for clogging gill and filtering mechanisms of aquatic organisms (e.g., fish gills).

Although engineering plans are still speculative, estimates indicate that over one billion cubic metres of landfill will be required to construct a dam across the opening between James and Hudson Bays.[3] The source of this landfill has not been identified, but the removal of such quantities is certain to have some detrimental impacts.

The transfer scheme itself could have severe implications for fisheries resources by restricting the movement of fish with dams and the possibility of entrainment and death of juvenile fish at pumping facilities, particularly at the James Bay source. Potential flooding along river valley corridors used for the water transfer would be accompanied by direct biological impacts and social disruption.

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(1) Ibid., p. 353-361.

(2) K. Kranck, Bedford Institute of Oceanography, personal communication, September 1985.

(3) A. Bruneau, The Grand Canal Scheme, notes presented during a meeting at the Bedford Institute of Oceanography, 7 January 1985, p. 2.

DISCUSSION

It is difficult to predict adequately the potential effects of terminating the freshwater flow of James Bay into Hudson Bay, when so little is known. Valiant attempts to model the oceanographic and atmospheric effects of partial diversions have been made in spite of an incomplete and inadequate database. Resource inventories of many biological entities which may be affected are also incomplete, although it is quite clear that a major portion of the North American migratory bird population would be negatively affected. As a consequence, most of the comments throughout the preceding text are speculative and were made on the premise of the construction of a dam across the entrance between Hudson and James Bays which would result in a total withdrawal of the freshwater of James Bay from Hudson Bay. This is only one possible scenario for the proposed "Grand Canal" scheme of which many parameters are still not defined. For example, what flow rate(s) will continue into Hudson Bay during which seasons? In an excessively moist or dry year, will the rates vary?

The examination of analogous situations and the modelling of this and other diversion projects have raised the concerns of possible long-term ecological and climatic effects. Particularly in conjunction with U.S.S.R. water diversions, how might possible major changes in the Arctic ice pack affect atmospheric circulation, temperature and precipitation patterns over the northern hemisphere? What will be the quality and extent of change in the freshwater signal entering the Labrador current, and what will be its effects? Downstream effects, which receiving areas of the diversions may encounter, have not been addressed but also warrant attention. These complex questions and countless others must be addressed before such a large-scale diversion is contemplated.

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